

## HOST INTERFACE FOR IMAGING ARRAYS

5           This application claims the benefit of US Provisional Patent Application Serial No. 60/177,496 filed on January 21, 2000.

### Field of the Invention

10           The invention relates generally to integrated electronic image sensing circuitry and more particularly to CMOS imaging circuitry.

### Background of the Invention

15           Integrated circuit (IC) technology, applied to imaging, is revolutionizing that field. Semiconductors can be used to represent an image as an electrical signal. Charge coupled devices (CCDs) are the most significant commercial IC technology to date. However, when compared with CMOS technology, there are many advantages to producing CMOS image devices.

20           CMOS is a less expensive technology; CMOS employs fewer mask layers and is a more mature fabrication technology with greater commercial volume. CCD technology complexity causes lower fabrication yield. One of the main benefits of employing CMOS technology, compared to CCD, is the ability to include image-  
25           processing elements on the same substrate as the imaging circuitry.

          On a monolithic semiconductor IC, with a surface coincident to an optical focal plane, photosensitive elements are employed in pixels that are arranged in an array of rows and columns. The basis for the pixels of CMOS technology is a  
30           photosensitive diode. In an active pixel arrangement each pixel photodiode is buffered from the shared readout components by an amplification stage.

IC image sensors of existing technologies provide video style output. In one example, such a sensor receives master clock input. The sensor derives data sample, line, and clocks from this master clock. These clocks, which correspond to pixel, row, and column, control the sampling rate of the imaging array. The pixel data of such a sensor is output at the same rate as it is sampled. The derived clocks are output as well to synchronize the data output. The result is a stream of synchronized pixel intensities comprising a video frame.

This output is incompatible with the data interface of commercial microprocessors, without the use of additional glue logic. A commercial microprocessor data interface consists of address and control output signals and data input/output signals. This configuration allows the processor to randomly access any word of data in memory by asserting various addresses.

In an image acquiring computer system based on such a sensor and such a processor, additional interface circuitry to respond to the sensor clock outputs to sample the video information, and to make this video data available in the memory space of the processor. Optionally, this interface circuit may include interrupt signals to the processor, and enough memory space for a number of pixels.

Such additional circuitry diminishes the benefit of a single substrate that integrates sensor and processing elements. The CMOS technology optimum cost benefit is not reached.

Therefore, there is a need for an interface which may be integrated with the imaging array which a system processor can access to directly receive imaging data.

## Summary of the Invention

This invention is directed to an interface for receiving data from an image  
5 sensor having an imaging array and a clock generator, and for transferring the data to  
a processor system. The interface comprises a memory for storing the imaging array  
data and the clocking signals at a rate determined by the clocking signals. In response  
to the quantity of data in the memory, a signal generator generates a signal for  
transmission to the processor system and a circuit controls the transfer of the data  
10 from the memory at a rate determined by the processor system. The memory may be  
a first-in first-out (FIFO) buffer or an addressable memory.

The signal generator may generate an interrupt signal for transmission to the  
processor system or a bus request signal for transmission to a bus arbitration unit for  
15 the processor system. The circuit for controlling the transfer of the data may include a  
command decoder for receiving address and command signals from the processor  
system, a configuration register for storing configuration data for the FIFO buffer and  
a read control for controlling the read-out of the FIFO buffer, and may further include  
a bus command unit for receiving control of the system bus and providing an address  
20 for the data read-out from the memory.

In accordance with another aspect of this invention, an integrated  
semiconductor imaging circuit for use with an electronic processing system having a  
data bus comprises an imaging array sensor having an array of sensing pixels and an  
array address generator integrated on a die and an interface integrated on the same  
25 die. The interface is adapted to receive data from the imaging array sensor as  
determined by the imaging array and to transfer the data to the electronic processing  
system as determined by the electronic processing system. The interface may include  
a memory such as a FIFO buffer or an addressable memory for storing imaging array  
data and address signals at a rate determined by the imaging array sensor, and a circuit  
30 for controlling the transfer of the data from the memory means to the data bus at a rate  
determined by the electronic processing system. The imaging circuit may further

include a bus arbitration circuit integrated on the same die and coupled to the circuit for controlling the transfer of the data.

5           In accordance with a further aspect of this invention, an integrated semiconductor imaging circuit for use with an electronic processing system having a data bus may comprise an imaging array of sensing pixels, a buffer for storing data received at an input port and for outputting data through an output port to the data bus, a circuit for transferring data from a selected pixel to the buffer input port, a  
10   circuit for determining the quantity of data in the buffer, a circuit for alerting the electronic processing system when the quantity of data in the buffer attains a predetermined level and a controller adapted to respond to the electronic processing system for controlling the transfer of the stored data through the buffer output port.

15           In accordance with another aspect of this invention, an integrated semiconductor imaging circuit for use with an electronic processing system having a data bus and a system address/control bus, may comprise an imaging array of sensing pixels, a buffer for storing data received at an input port and for outputting data through an output port to the data bus, a circuit for transferring data from a selected  
20   pixel to the buffer input port, a circuit for determining the quantity of data in the buffer, a controller for seeking control of the data bus when the quantity of data in the buffer attains a predetermined level and adapted to respond to the availability of the data bus for controlling the transfer of the stored data through the buffer output port. The integrated semiconductor imaging circuit may further include a bus arbitration  
25   unit for receiving data bus control requests and for providing data bus control in response to a request, and the controller for receiving bus control comprising a register for storing and incrementing destination addresses, and a circuit for asserting the destination address and write controls on the system address/control bus.

30           In accordance with a further aspect of this invention, an integrated semiconductor imaging circuit for use with an electronic processing system having a data bus, may comprise an imaging array of sensing pixels, an addressable memory

having a plurality of memory cells arranged in rows and columns for storing data received at an input port and for outputting data through an output port to the data bus, a circuit for transferring data from a selected pixel to a selected memory cell  
5 through the memory input port, a circuit for determining the quantity of data in the memory, a circuit for alerting the electronic processing system when the quantity of data in the memory attains a predetermined level, and a controller adapted to respond to the electronic processing system for controlling the transfer of the stored data through the memory output port.

10

In accordance with another aspect of this invention, an integrated semiconductor imaging circuit for use with an electronic processing system having a data bus and a system address/control bus, may comprise an imaging array of sensing pixels, an addressable memory having a plurality of memory cells arranged in rows  
15 and columns for storing data received at an input port and for outputting data through an output port to the data bus, a circuit for transferring data from a selected pixel to a selected memory cell through the memory input port, a circuit for determining the quantity of data in the memory, and a controller for seeking control of the data bus when the quantity of data in the memory attains a predetermined level and adapted to respond to the availability of the data bus for controlling the transfer of the stored data through the memory output port. The integrated semiconductor imaging circuit may further include a bus arbitration unit for receiving data bus control requests and for providing data bus control in response to a request, and the controller for receiving  
20 bus control comprising a register for storing and incrementing destination addresses, and a circuit for asserting the destination address and write controls on the system address/control bus.

Other aspects and advantages of the invention, as well as the structure and operation of various embodiments of the invention, will become apparent to those  
30 ordinarily skilled in the art upon review of the following description of the invention in conjunction with the accompanying drawings.

## Brief Description of the Drawings

The invention will be described with reference to the accompanying drawings,  
5 wherein:

**Figure 1** is a block diagram of a computer system utilizing the imaging array sensor;

**Figure 2** is a block diagram of an imaging array sensor including the interface of the present invention;

10 **Figure 3** is a block diagram of the pixel imaging array and access;

**Figure 4** is a block diagram of the video clock and array address generator;

**Figure 5** is a block diagram of a FIFO buffer;

**Figure 6** is a block diagram of a computer system with bus arbitration utilizing the imaging array sensor;

15 **Figure 7** is a block diagram of an imaging array sensor that includes an interface having bus arbitration circuitry; and

**Figure 8** is a block diagram of an imaging array sensor that includes an interface having an addressable memory.

## 20 Detailed Description of the Invention

The imaging computer system illustrated in **figure 1** includes a central processing unit (CPU) 10, other memory and system components 11, an imaging array sensor 12, an interface 13 in accordance with the present invention and a video  
25 clock generator 14. The CPU 10, components 11 and interface 13 all have access to a system data bus 15 and are controlled by the CPU 11 via the system control and address bus 16. The clock generator 14 provides pixel clock signals  $C_p$  to the imaging array sensor 12. The interface 13 is further connected to the CPU 10 through an interrupt bus 17 by which the CPU 10 is signalled that data is available for it to  
30 upload.

In accordance with the present invention, the interface 13 stores data and clocking signals from the imaging array sensor 12 in order to free up the CPU 10 for other processing. In addition, the full economic and commercial advantage of CMOS technology may be gained by integrating the interface 13 on the same die as the imaging array sensor 12.

An embodiment of the interface 13 is illustrated as a block diagram in figure 2. The imaging array sensor 12 includes an imaging array 21 which is an array of active photosensitive pixels with access control as will be described further with reference to figure 3. The imaging array 21 further includes an array address generator 22 which generates the column addresses  $A_C$ , the row addresses  $A_R$ , the row clock  $C_R$  and the frame clock  $C_F$  as will be described further with reference to figure 4.

Referring to figure 3, the array 30 of pixels 33 is organized in rows 31 and columns 32. Each pixel 33 is located at the intersection of a row 31 and a column 32. The row control lines 34 provide access to a row 31 of pixels 33. The row line 34 is driven by the row drivers 35 in response to the row address signal  $A_R$ . Each selected pixel 33 asserts data onto its own column data line 36 when accessed. The data on lines 36 is amplified by column amplifiers and second stage amplification in unit 37. Unit 37 further selects the column 32 as determined by column address  $A_C$  from which array data  $D_A$  is placed on the array output 38.

Referring to figure 4, the array address generator 22 is shown in greater detail. The column address  $A_C$  is generated by a column counter 41 which is incremented by the video system clock  $C_P$ . The maximum number of sequential addresses generated by the column counter 41 will depend on the number of columns in the imaging array 21, however the actual number of sequential addresses generated by the column counter 41 will be determined by the column boundary signal  $B_C$  which is controlled by the CPU 10 as will be described later. The row clock  $C_R$  is generated by the overflow of the column counter 41. The row counter 42 generates the row address

signal  $A_R$  based on the row clock signal  $C_R$  and the row boundary signal  $B_R$ . The maximum number of sequential addresses generated by the row counter 42 will depend on the number of rows in the imaging array 21, however the actual number of sequential addresses generated by the row counter 42 will be determined by the row boundary signal  $B_R$  which is controlled by the CPU 10 as will be described later. The row clock  $C_R$  is also applied to an output 43 from the array address generator 22. The row counter 42 also generates a frame signal  $C_F$  based on count overflow.

Referring again to **figure 2**, the interface 13 includes a memory 44 as well as devices 45 to 49 required to support the memory 44. In this particular embodiment, memory 44 is a first-in first-out (FIFO) buffer memory. FIFO buffer 44 receives array data  $D_A$  from the imaging array, clocking signals  $C_P$  from the video clock generator 14 and clocking signals  $C_R$  and  $C_F$  from the array address generator 22. FIFO buffer 44 is shown in greater detail in **figure 5**. The imaging array 21 output  $D_A$ , row clock  $C_R$  and frame clock  $C_F$  are bundled onto a single bus 51 for storage in the buffer 44. The storage components of the FIFO buffer 44 are registers 52 arranged as a shift register series 53. Since the total number of valid outputs may vary due to the differing rates of storage and access, the bus 51 is connected to each register 52. An increment/decrement counter 54 is used to count the occurrences of FIFO buffer 44 writes and FIFO buffer 44 reads. Counter 54 has access to the pixel clock  $C_P$  and a FIFO read signal  $S_R$ . The FIFO counter 54 output  $S_C$  is applied to buffer output 55 and to the Register address decoder 56. The decoder uses the counter output  $S_C$  and pixel clock  $C_P$  in determining when to assert the appropriate register write signal on lines 57. The read signal  $S_R$  is connected to the shift registers 52 to shift the registers by a number of registers depending on the read signal  $S_R$  value. The same number of registers, from the end of the buffer, asserts data  $D_I$  on the system data bus 15 during this operation.

There are basically three types of FIFO buffers, each of which may be used with the present invention. The first type of buffer 44 is the one shown in **figure 5** where stored data is removed from buffer register series 53 from the first register 53



on the right hand end and data from the bus 51 is written into the last available shift register 52 from the left end of the buffer register series 53. A second type of buffer is one where the data is written into the first register on the left hand end of the buffer register series and data is taken out of the buffer register series from the first register with data in the series looking at it from the right end of the register series. The third type of buffer is one in which data from the data bus is written into the last available shift register looking from the left end of the buffer register series and data is taken out of the buffer register series from the first register with data in the series looking at it from the right end of the register series. In all three cases, data is removed from the buffer in the same sequence that it is entered into the buffer.

Referring again to **figure 2**, the interface 13 includes devices 45 to 49 to support the FIFO buffer 44. The devices include a Chip Command Decoder 45, FIFO Configuration Registers 46, FIFO Read Control, an Interrupt Generator 48 and Array Registers 49.

The CPU 10 accesses the registers 46 and 49 and FIFO buffer 44 through the Chip Command Decoder 45 by asserting the necessary read or write commands, along with the address on the system address and command bus 16. The command decoder 45 identifies any buffer or register being addressed and asserts the necessary read or write signal on the FIFO read control 47 line 56, the FIFO configuration register 46 command bus 57, or the array register 49 command bus 58. The signal on line 56 permits the FIFO read control 47 to generate a FIFO read signal  $S_R$  in response the output bus width signal  $S_{BW}$ . Variation of the FIFO 44 output bus width register provides compatibility with a variety of system bus configurations such as 8-bit or 32-bit.

The FIFO configuration registers 46 include the FIFO output bus width, the FIFO limit value, the FIFO interrupt mask, and the FIFO interrupt register. All of these registers are connected to the system data bus 15 and are read/write capable, except the FIFO interrupt register, which is read only and determines its value from

the interrupt generator as signal  $S_I$ . The reading and writing of these registers is controlled by the FIFO register command bus 57. The output of the FIFO configuration registers include FIFO limit signal  $S_L$  from the FIFO limit register, the interrupt enable signal  $S_E$  from the FIFO interrupt mask, and the output bus width signal  $S_{BW}$  from the FIFO output bus width register.

The interrupt generator 48 compares the FIFO counter output  $S_C$  and the FIFO limit  $S_L$ . If  $S_C \geq S_L$  and if the interrupt enable signal  $S_E$  is valid, the generator 48 asserts the interrupt signal  $S_I$  to the CPU 10 via the interrupt bus 17. The use of an interrupt signal  $S_I$  as an interrupt to the CPU 10 allows the processor to multi-task. It performs a buffer 44 unload operation when the interrupt is asserted, and carries out other programmed tasks at all other times.

Access to the array registers 49 is controlled by the array register command bus, 58. Data is exchanged with the system data bus 15. The content of the registers 49 defines the number of rows and columns to be employed in the imaging array 21. This information is communicated to the array address generator 22 by the row and column boundary signals  $B_R$  and  $B_C$ .

The above interface 13 signals the CPU 10 through the interrupt signal  $S_I$  when it has an amount of data approaching the limits of its storage capacity. The CPU then responds by having the data downloaded onto the system bus 15. It is important for the CPU to respond to the interface faster than the imaging array 21 can generate data. In addition, the size of the FIFO buffer 44 will also depend on the latency of the CPU 10, since during the period of time required by the CPU 10 to respond to the interrupt signal  $S_I$ , data is being stored in the buffer 44. The faster that the CPU 10 is able to respond to the interrupt and accept the downloaded data, the smaller the buffer 44 can be and the less space that it will require if integrated on the die with the imaging array 21. However, in real time control applications, it is important that the interface 13 and the CPU 10 be matched so that the data from all frames scanned by the imaging array 21 is properly and completely transferred to the

CPU 10. This requirement may be relaxed somewhat for camera type applications where the necessity of capturing all frames is not required.

5 In a further embodiment of the present invention as illustrated in **figure 6**, the interface 73 would interact with the CPU 10 and other system components through a bus arbitration unit 61. Rather than send an interrupt signal  $S_I$  to the CPU 10, the interface 73 sends a bus request signal  $S_{BR}$  to the bus arbitration unit 61 and receives an arbitration acknowledgement signal  $S_{AA}$  when the bus 15 is available to it for  
10 downloading data. As illustrated in **figure 6**, the other units, CPU 10 and components 11 in the system have their own arbitration request lines 62 and arbitration acknowledgement lines 63. The Bus Arbitration Unit 61 receives all the requests for the bus 15 and selects one unit that is acknowledged as the current bus master.

15 The required components in the interface 73 that are required in order for it to be compatible with a bus arbitration system are shown in **figure 7**. A Bus Request Generator 64 functions in the same manner as the Interrupt Generator 48 shown in **figure 2**. A bus request signal  $S_{BR}$  is generated in the same manner as the interrupt  $S_I$ . If  $S_C \geq S_L$  and the bus request enable signal  $S_{BE}$  is valid, the generator 64 asserts the  
20 bus request signal  $S_{BR}$  to the bus arbitration unit 61.

An arbitration acknowledge signal  $S_{AA}$  notifies the interface 73 that the interface 73 may assert command of the bus 15. The arbitration acknowledge signal  $S_{AA}$  is applied to the chip command decoder 45 and a bus command unit 65. The  
25 arbitration acknowledge signal  $S_{AA}$  deactivates the command decoder 45 for the duration that the interface controls the bus 15. On receiving the arbitration acknowledge signal  $S_{AA}$ , the bus command unit 65 will activate an output address unit 66 via the request output address signal  $S_{AR}$  and receive from it the next address on the output address signal  $S_{AN}$ . This address is sent out onto the system address and  
30 control line 16. At the same time the bus command unit 65 asserts the necessary read or write signal on the FIFO read control 47 line 67.

The address may represent a location in the CPU 10, however, one advantage of this arrangement is that the address may be to a location in one of the system components 11 such as a memory so that the data may be stored in the system for processing by the CPU 10 without the CPU 10 being disturbed to make the transfer. The output address unit 66 contains a register and increment circuit for the purpose of recording and updating this address. The addresses in the output address unit 66 are transferred to the address registers through bus 15 under the control of a signal from CPU 10 on the system control and address bus 16 through command decoder 45.

As stated previously, the imaging array sensor 12 and the interface may be integrated onto one die. However, in addition, the Bus Arbitration Unit 61 may also be integrated onto the same die, and thus the bus arbitration request and acknowledge signals on lines 62 and 63 become external signals of the integrated unit.

In a further embodiment of the present invention, the memory in the interface 83 may be an addressable memory 81 as shown on figure 8. For purposes of writing to memory 81 from the imaging array 21 the row and frame clocks  $C_R$  and  $C_F$  serve as row and column addresses. The video system clock  $C_P$  serves as a write clock. Thus the memory 81 records the imaging array output  $D_A$  at the same rate as the imaging array 21, and in the same array order as the imaging array 21.

For reading purposes, the read control signal  $S_R$  provides the necessary address information, bus width information and read control timing. The memory read control 82 derives this information from the memory configuration registers 84 via the output bus width signal  $S_{BW}$  and from the command decoder 45 via the read enable and read address bus 16 and through line 85. The memory configuration registers 84 are identical to the FIFO configuration registers 46. The memory 81 also includes an increment/decrement counter similar to counter 54 to interface with the interrupt generator 48. In addition, the interface 83 may be adapted for use with a bus arbitration unit 61 in the same manner that the interface 73 has been adapted as described in conjunction with figure 7.

Though the use of an addressable memory 81 in interface 83 does not provide the size, simplicity and lower cost of a FIFO memory, the fact that the memory is addressable allows the CPU to select parts or patterns from each frame for processing  
5 though the memory 81 would normally hold one frame which would be refreshed with each scan.

While the invention has been described according to what is presently considered to be the most practical and preferred embodiments, it must be understood  
10 that the invention is not limited to the disclosed embodiments. Those ordinarily skilled in the art will understand that various modifications and equivalent structures and functions may be made without departing from the spirit and scope of the invention as defined in the claims. Therefore, the invention as defined in the claims must be accorded the broadest possible interpretation so as to encompass all such  
15 modifications and equivalent structures and functions.